Valley Phase Transition in Si MOSFETs

The recent detailed experiments on high mobility Si MOSFETs [1,2] have convincing supports for the existence of a phase transition at low densities around a sample-dependent value of $n_s = 1 \times 10^{11}\,\mathrm{cm}^{-2}$. This density translates to $r_s = 8.64$ where $r_s = 1/a_B^* \sqrt{\pi n_s}$ and a_B^* is the effective Bohr radius. The driving mechanism of the transition is, however not yet resolved. The role of superconductivity in this connection is suggested recently by several groups [3,4]. Other theoretical works characterized the insulator phase as the disorder driven electron solid [5] and metastable frozen electron solid [6]. We would like to contribute to this on-going discussion by suggesting the possibility of a valley phase transition.

Originally, Bloss, Sham and Vinter [7] put forward the idea of a valley phase transition in Si(100) inversion layers having two degenerate valleys, that initiated some theoretical and experimental activity in the beginning of 1980's [8,9]. The driving mechanism of this transition is many-body in origin: stacking the available inversion layer electrons just to one of the valleys (degenerate in single-electron level) increases the total kinetic energy as well as the intravalley exchange energy. However, the exchange energy is negative and towards lower electronic densities, this single valley occupation becomes the ground state. Based on the density functional calculations, Bloss *et al.* predicted the valley phase transition density to be around $n_s = 3 \times 10^{11}\,\mathrm{cm}^{-2}$. They also conjectured the low density phase (i.e., $n_s < 3 \times 10^{11}\,\mathrm{cm}^{-2}$) to have thermally activated conductivity due to formation of spatial domains where the populated valley toggles abruptly, as in ferromagnetic materials. To verify these theoretical claims, Cole *et al.* [8] performed intersubband transition experiments on Si(100) MOSFETs, and *only for the high mobility ones*, they registered a change in the slope of the subband transition energy around $5 \times 10^{11}\,\mathrm{cm}^{-2}$ in the direction that complies with the valley phase transition explanation. The conductivity was observed to be thermally activated for densities lower than $2 \times 10^{11}\,\mathrm{cm}^{-2}$. The following calculations of Isihara and Ioriatti [9] on the ground state energies of the 2D electron gas having single and double valley degeneracies confirmed that for $r_s > 8.011$ single valley occupation becomes lower in energy than the equal population.

These available results in the past literature seem to be relevant with the recently observed effects in Si MOSFETs [1,2]. The possibility of a valley phase transition can be experimentally checked in these MOSFET samples by probing the valley degeneracy on either side of the transition density. Furthermore, it will be interesting to see the results of the same detailed experiments for the GaAs/AlGaAs HEMTs having a valley degeneracy of one; in turn, a phase transition ruled by exchange interactions along the same lines can only be due to spin degeneracy, leading this time to a *ferromagnetic* state beyond some density. However, regardless of the validity of the valley phase transition picture for the driving mechanism, much more theoretical and experimental labor is required to clarify the observed metallic-like and insulator-like phases.

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